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Ageing of the Insensitive Explosive, ARX-4024

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ABSTRACT

An accelerated ageing program was undertaken to analyse the suitability of ARX-4024 as a replacement for Composition B in Australian munitions. Testing was undertaken utilising two different conditions, namely the B2 cycle, which is representative of extreme conditions in northern Australia, and at a constant 60°C with ambient humidity.

An analysis of the ingredient composition, sensitiveness, and mechanical strength was made at 3 month intervals over a period of 12 months, and the results compared to Composition B samples similiarly aged.

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Ageing of the Insensitive Explosive, ARX-4024

Executive Summary

An accelerated ageing program was undertaken to analyse the suitability of ARX-4024 as a replacement for Composition B in Australian munitions. ARX-4024 is a melt-cast explosive consisting of 35% TNT mixed with 65% of a bimodal NTO mixture. Testing was undertaken utilising two different conditions, the B2 cycle, which is representative of conditions in northern Australia, and at a constant 60°C with ambient humidity.

An analysis of the ingredient composition, sensitiveness, and mechanical strength was made at 3 month intervals over a period of 12 months, and the results compared to Composition B samples similiarly aged.

Results indictated that accelerated ageing of ARX-4024 samples showed no adverse effects compared to similarly aged Composition B samples. Other than the expected TNT loss, there was no major change in the composition of ingredients, and hazards testing revealed only minor changes to sensitiveness. Mechanical strength testing showed a decrease in mechanical strength with time, however compared to Composition B this change was minor.

Accelerated ageing of ARX-4024 has shown that this material should be an ideal replacement for Composition B in artillery projectiles utilised by the ADF.

Contents

1. Introduction

Current research has led to the development of the Insensitive Munition (IM) main charge explosive ARX-4024 for use in gun fire projectiles such as the 5"/54 Naval artillery round and 81 mm mortar [1,2]. Assessment has included examination of its processability [3], IM compliance [4], lethality and fragmentation [5], and gun launch survivability [7]. However, further analysis was required to examine its ageing characteristics.

This accelerated ageing program was undertaken to analyse the suitability of ARX-4024 as a replacement for Composition B in Australian munitions. Testing was undertaken utilising two different conditions. Heating at a constant 60°C with ambient humidity was utilised as the first condition set, this representing the highest temperature considered safe for the testing program. The second condition set employed was the B2 cycle, representative of a very severe but appropriate upper temperature and humidity cycle that the ARX-4024 fill could be expected to experience for a reasonable period of time within its service life [8].

An analysis of the ingredient composition, sensitiveness, and mechanical strength was made at 3 month intervals over a period of 12 months, and the results compared to Composition B samples similiarly aged.

2. Background

The melt-cast explosive ARX-4024, consisting of 65:35 NTO/TNT, has been extensively investigated as an IM replacement for Composition B for use in gun launch projectiles as it possesses similar explosive output, while being intrinsically less sensitive to hazards stimuli than Composition B [1-5]. Its performance has been characterised, and its sensitivity determined through insensitive munitions tests. The key sensitivity and performance data for ARX-4024 are given in Table 1, and are compared to the current in-service 5"/54 main charge containing Composition B, and PBXN-107, the latter a polymer bonded explosive artillery shell main charge fill assessed in the 5"/54 round by DSTO in the early 1990s [6].

Table 1. Explosive Properties of ARX-4024 and Composition B

Property	ARX-4024	Composition B	PBXN-107A
VoD (m/s)	7810	7890	8160
P_{CJ} (GPa)	25.9	28.7	-
D_{crit} (mm)	17.8 – 20.0	3 – 4	8
Density (g/cm)	1.80	1.71	1.6
LSGT			
- Shock Sensitivity (GPa)	5.24	2.69	4.2
- PMMA Gap (mm)	26.4	45.9	36.5
Cookoff Response (SSCB)			
- fast heating	Deflag	Detonation	Mild Burn
- slow heating	Burn - Deflag	Detonation	Deflag
Cookoff Response (SCB)			
- fast heating	Deflag - Expl	Detonation	-
- slow heating	Expl	Detonation	-

ARX-4024 shows considerable reductions in shock sensitivity over both Composition B and PBXN-107A. Cook-off tests for Composition B in both SSCB and SCB resulted in high order events with complete consumption of the explosive. However, in comparison, cook-off response of ARX-4024 showed reduction of event severity, generally with recovery of quantities of unconsumed explosive. When compared to PBXN-107A, ARX-4024 shows similar responses, with a slightly more severe response noted under fast heating conditions, and a slightly less severe response noted for the slow cook-off experiment.

Previous work has shown ARX-4024 to possess improved preliminary IM properties while still maintaining comparable performance to both Composition B, the current 5”/54 fill, and PBXN-107A, a previously examined 5”/54 main charge IM replacement.

3. Ageing Conditions

One-inch diameter sticks of ARX-4024 and Composition B were manufactured on site. From each stick the bottom 3 pellets were used for mechanical testing, the next pellet for sensitiveness testing and the final for ingredient analysis. For each time period of the ageing program, samples in identical positions were compared. Additional pellets were supplied from the remains of the longer sticks for repeat testing if required. One stick would supply the samples required for one set of conditions per time period.

Bare samples were placed on an open oven tray, which was in turn placed in ovens set to provide the required ageing conditions. No attempt to confine or cover the pellets was made.

One set of samples was held at a constant temperature of 60°C in an oven at DSTO Edinburgh with no humidity control. This represented the most severe temperature conditions possible while still maintaining safe test conditions.

The second set of samples was placed in an environmental chamber at P&EE Pt Wakefield and subjected to the B2 cycle, and conditioned in accordance to DEF(Aust)5168 [8]. The B2 cycle consists of offset temperature and humidity cycles over 24 hours. Temperature cycles between 31 and 63°C while relative humidity cycles between 12 and 75% (Figure 1)

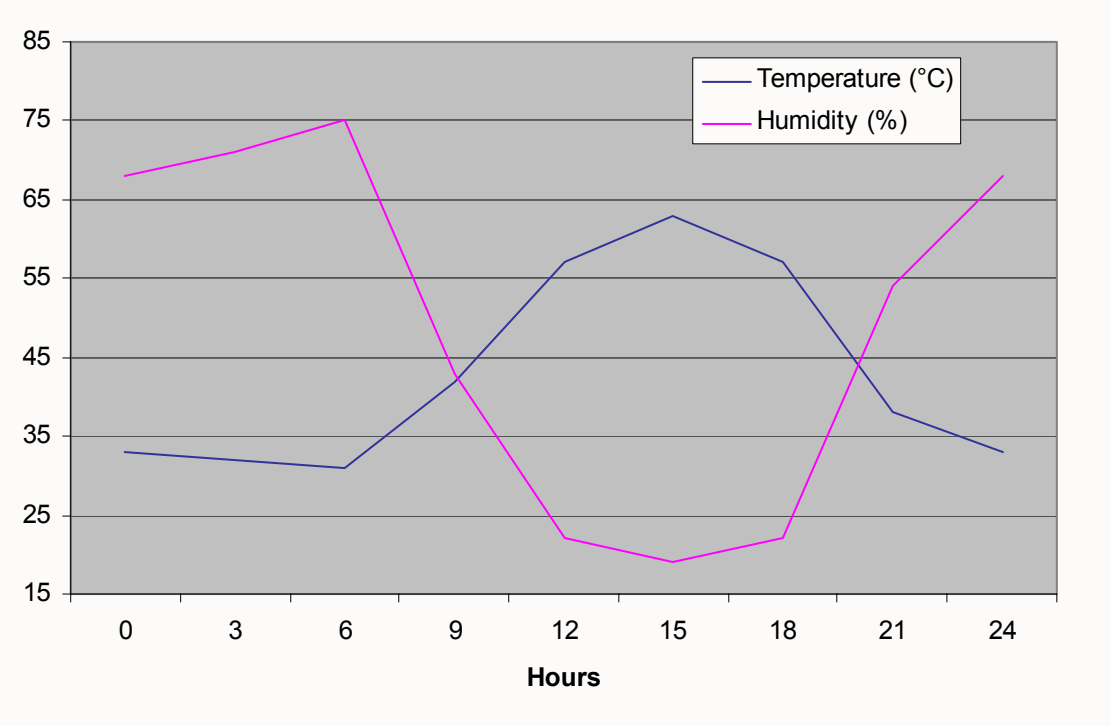

Figure 1. B2 Ageing Cycle

4. Ingredient Analysis

Assessment of the contents was made for a sample from each group to ensure the ratio of TNT to NTO or RDX did not deviate more than expected. At elevated temperatures TNT will sublime from the samples, so the amount of recovered TNT following analysis was compared to the theoretical amount of TNT assuming no sublimation, calculated from the amount of filler remaining.

To measure the amount of each ingredient, a pellet (~20 grams for ARX-4024, compared with ~18 grams for Composition B) was placed into a beaker of benzene (100mL) and stirred for an hour. The mother liquor was decanted through filter paper and collected.

This process was then repeated twice on the solid remaining after decanting, and the mother liquors collected.

The residual solid was then placed in a rotary evaporator to remove any remaining solvent and dried under vacuum. The material was weighed with the dried contents from the filter paper to give the total solids content for the pellet (ie the amount of RDX or NTO) (Figure 2).

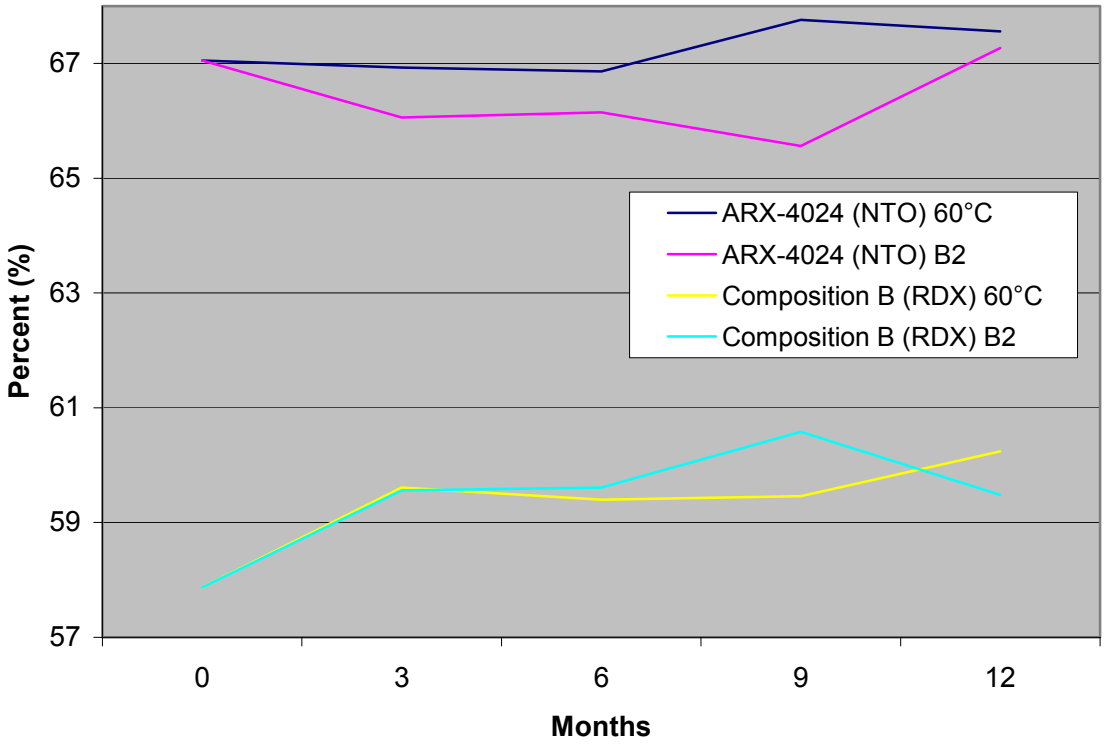

Figure 2. NTO/RDX Content following ageing of ARX-4024 and Composition B

The collected mother liquors were rotary evaporated to dryness, and then placed under vacuum to remove any remaining solvent. The dried material was weighed to give the TNT content for the pellet (Figure 3).

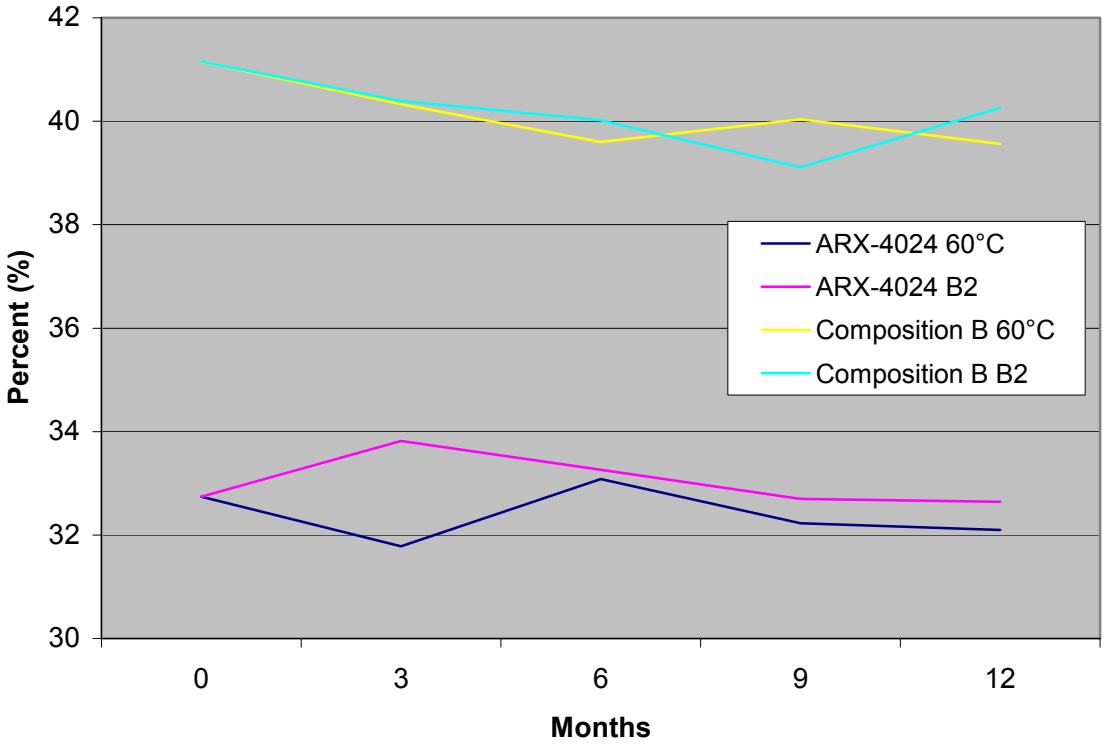

Figure 3. TNT Content following ageing of ARX-4024 and Composition B

As expected there is a small loss of TNT, however this is not expected to create any major stability problems for this material throughout its service life. It should also be noted that the overall loss of TNT from ARX-4024 is less than the loss from Composition B. Raw data is presented in Table 2.

Table 2. Raw data from Ingredient Analysis (values represent percentage of pellet mass)

	0 Months	3 Months		6 Months		9 Months		12 Months	
		60°C	B2	60°C	B2	60°C	B2	60°C	B2
ARX-4024									
NTO	67.05	66.93	66.09	66.86	66.15	67.76	65.56	67.56	67.27
TNT	32.74	31.78	33.82	33.08	33.26	32.23	32.70	32.10	32.64
Composition B									
RDX	57.87	59.61	59.56	59.40	59.61	59.46	60.58	60.24	59.48
TNT	41.15	40.33	40.39	39.60	40.02	40.04	39.11	39.56	40.26

5. Sensitiveness

Sensitiveness testing was undertaken for both formulations under each ageing condition at 3 month periods. Rotter Impact (Table 3), BAM Friction (Table 4), Temperature of Ignition (Table 5) and Electrostatic Discharge tests were conducted. Little change was noted for any of the tests, with no discernable change noted for the ESD test (all results showed ignition at 0.45J but not at 0.045J).

Table 3. Rotter Impact Results.

	0 Months	3 Months	6 Months	9 Months	12 Months
ARX-4024					
B2	200	>220	190	200	>220
60°C	200	>220	>220	210	190
Composition B					
B2	110	170	170	200	180
60°C	110	130	150	190	140

Table 4. BAM Friction Results (N)

	0 Months	3 Months	6 Months	9 Months	12 Months
ARX-4024					
B2	84	80	120	120	120
60°C	84	108	120	120	120
Composition B					
B2	108	80	80	108	108
60°C	108	72	80	84	84

Table 5. Temperature of Ignition Results (°C)

	0 Months	3 Months	6 Months	9 Months	12 Months
ARX-4024					
B2	252	252	252	254	264
60°C	252	252	252	252	252
Composition B					
B2	212	213	210	212	213
60°C	212	212	212	201	202

Analysis of the sensitiveness data gathered during the accelerated ageing test period suggests that ARX-4024 should not become more sensitive to hazardous stimuli through it's service life. Sensitiveness remains relatively constant regardless of ageing conditions and time duration. Results compare favourably to those seen for the current Composition B fill used in artillery projectiles.

6. Mechanical Testing

Three samples from each material were assessed at three monthly intervals for both ageing conditions using compression testing. An Instron 5500R1185 Universal Testing Machine was utilised with a 100kN load cell set to a crosshead rate of 1 mm/min.

The results show ARX-4024 has greater mechanical strength than Composition B. This supports the anecdotal evidence garnered during machining processes for tests leading up to this point, where it was noted that ARX-4024 was much harder to machine than Composition B.

Interestingly, visual examination of the 60°C and B2 cycle samples seems to indicate greater deterioration of the 60°C samples. However, analysis of the mechanical testing results (Tables 6 and 7) confirmed the expected result that the thermal cycling of the B2 samples was more severe. The samples held at 60°C darkened significantly faster than the samples subjected to the B2 cycle. Additionally, the 60°C samples appeared to become rougher and more particulate on the exposed surfaces than their corresponding B2 samples, thought to be due to TNT loss.

Table 6. 60°C Mechanical Testing

	0 Months	3 Months	6 Months	9 Months	12 Months
ARX-4024					
Max. Load (kN)	14.13	14.64	13.61	11.92	10.17
Standard Deviation	0.56	1.23	1.33	0.10	0.64
Modulus (Mpa)	1936.49	1741.7	1567.14	1421.29	1252.2
Standard Deviation	89.10	145.54	79.74	29.33	38.15
Compression at Max. Load (mm)	0.38	0.4	0.47	0.47	0.46
Standard Deviation	0.01	0.01	0.04	0.02	0.01
Composition B					
Max. Load (kN)	7.23	7.15	7.56	6.84	6.2
Standard Deviation	0.11	0.44	0.79	0.98	0.76
Modulus (Mpa)	1607.12	1524.31	1260.2	1262.38	1149.83
Standard Deviation	23.83	61.53	113.05	63.63	83.87
Compression at Max. Load (mm)	0.23	0.24	0.33	0.3	0.32
Standard Deviation	0.01	0.01	0.02	0.01	0.01

Under 60°C ageing conditions ARX-4024 showed an overall decrease in maximum load of 28%, while Composition B showed a decrease of 14%, half that of ARX-4024. While the ARX-4024 decrease is greater than that for Composition B, the overall mechanical strength is still much greater than that for the Composition B standard.

As expected, there is a decrease in compressive strength for both ARX-4024 and Composition B during the entire year of B2 cycle accelerated ageing regime. Over the

period of examination, the compressive strength of the material dropped substantially. However, while the Composition B maximum load dropped by over 70%, the maximum load for ARX-4024 only dropped 58% (Table 7).

Table 7. B2 Cycle Mechanical Testing

	0 Months	3 Months	6 Months	9 Months	12 Months
ARX-4024					
Max. Load (kN)	14.13	12.09	8.33	6.89	5.89
Standard Deviation	0.56	0.81	1.81	0.96	2.89
Modulus (Mpa)	1936.49	1626.11	1077.33	847.09	894.24
Standard Deviation	89.10	141.81	194.37	98.46	169.66
Compression at Max. Load (mm)	0.38	0.37	0.43	0.45	0.36
Standard Deviation	0.01	0.00	0.02	0.05	0.09
Composition B					
Max. Load (kN)	7.23	5.3	3.87	2.97	1.97
Standard Deviation	0.11	0.5	0.29	0.04	0.26
Modulus (Mpa)	1607.12	1279.31	737.47	573.3	518.88
Standard Deviation	23.83	47.25	57.54	41.75	82.15
Compression at Max. Load (mm)	0.23	0.22	0.29	0.3	0.2
Standard Deviation	0.01	0.01	0.01	0.01	0.01

While a decrease in mechanical strength was still noted for both samples during the test period, comparison of the 60°C data with that produced under the B2 Cycle indicated that the mechanical strength of ARX-4024 was retained to a greater degree under 60°C ageing conditions (Figure 4-6).

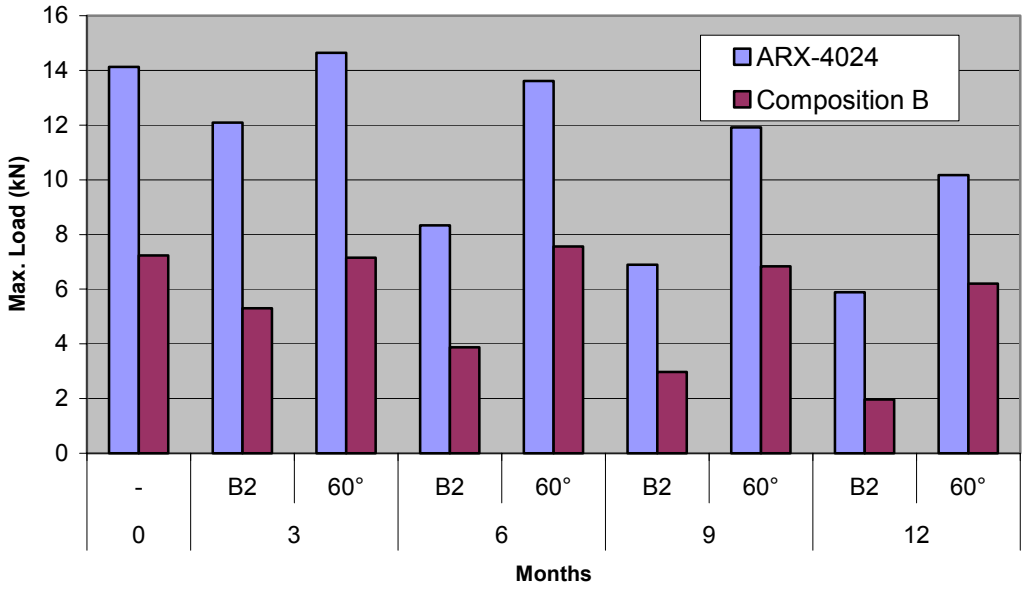

Figure 4. Maximum Load for ARX-4024 and Composition B

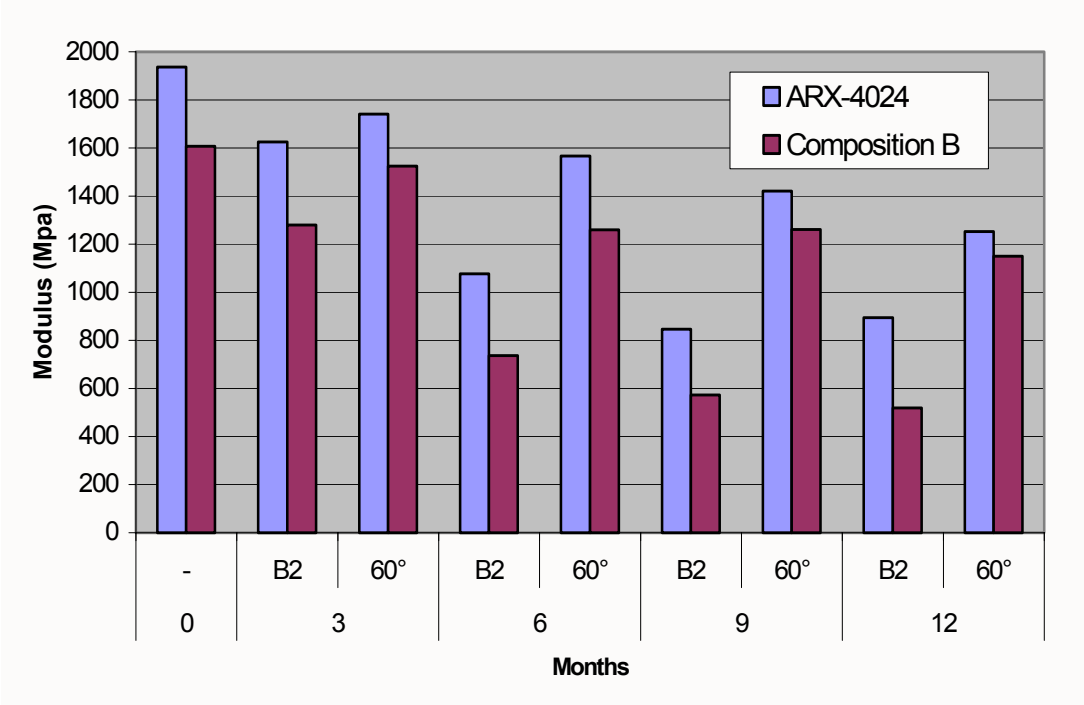

Figure 5. Comparison of Modulus for aged ARX-4024 and Composition B

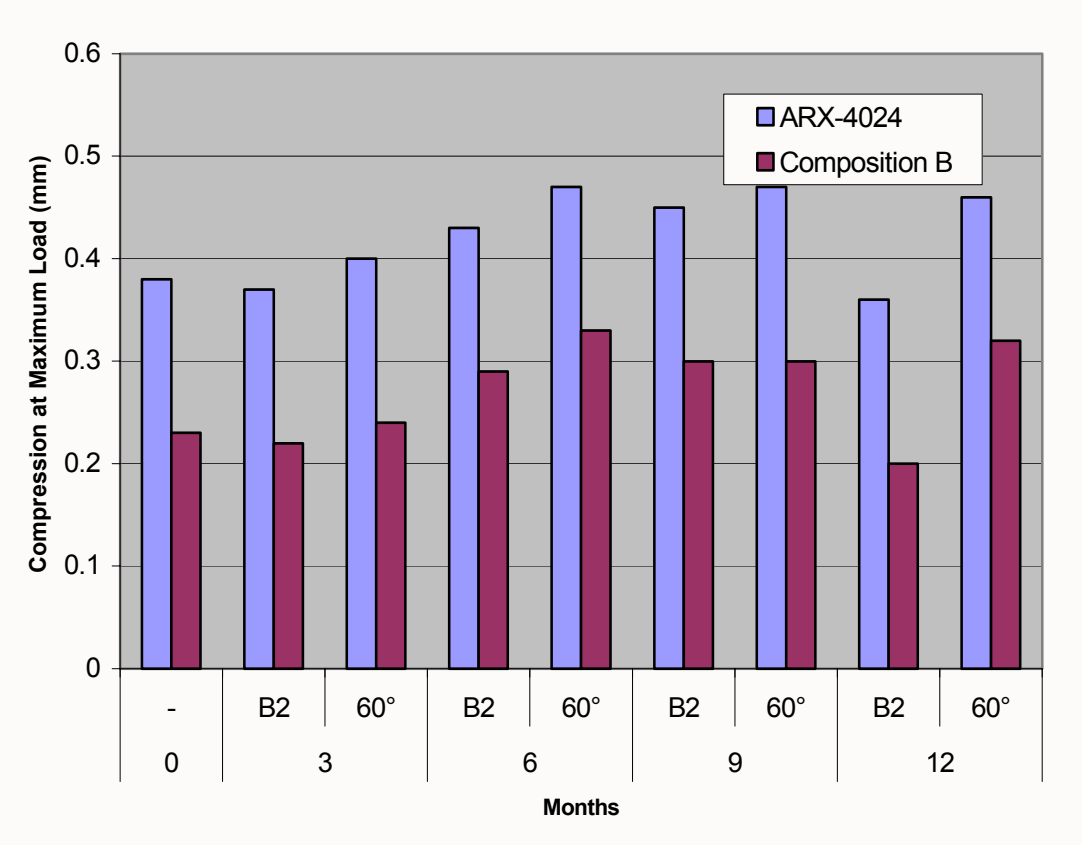

Figure 6. Comparison of Compression at Maximum Load for Aged ARX-4024 and Composition B

7. Conclusions

ARX-4024 was subjected to accelerated ageing conditions for a full year, and its behaviour compared to that of Composition B, similarly aged. The ageing regimes selected included one set of samples at 60°C and ambient humidity, and one set under the B2 cycle of cyclic temperature and humidity.

An analysis was made of the ingredient composition, samples sensitiveness, and mechanical strength, and an assessment made on the suitability of ARX-4024 as a Composition B replacement.

All tests showed ARX-4024 to behave in a superior manner. While there was a small degradation in component ratios and mechanical strength, this degradation was less than that seen for Composition B.

There was negligible change in impact, friction, electrostatic discharge and temperature sensitiveness over time.

Thus ageing of ARX-4024 has compared favourably with Composition B, and this explosive should be a suitable insensitive replacement for Composition B in Australian artillery projectiles.

8. Acknowledgements

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